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Real And Reactive Power Control Of Doubly Fed Induction Generator During Voltage Sag

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Abstract

The number of wind energy installations is rapidly growing worldwide. With increasing wind power production, it is important to predict the grid interaction of wind turbines. A wind energy conversion system with the doubly fed induction generator is most frequently used topology due to the combination of variable-speed operation and a cost-effective partially rated power converter. But it is very sensitive to grid disturbances due to direct connection of stator to the grid. A simple solution is automatic disconnection of plant from the grid, but this will lead to a massive power-network failure. Comparison of DFIG, SCIG and SG are presented. This paper presents a method to tune the controller to make DFIG more rigid for remote faults. The simulated result shows the real and reactive power flow control to the grid during fault condition.

Keywords: **Doubly Fed Induction Generator (DFIG), ETAP, voltage sag, wind power generation.**

1. Introduction

The increasing global fuel price has resulted in increasing focus on renewable resources. Among renewable resources, wind energy and Hydro energy is emerging technology. Wind power is the conversion of wind energy into electricity using wind turbines. The wind is free and with modern technology it can be captured efficiently. Once the wind turbine is built, the energy that produces does not cause green house gases or other pollutants. In India, overall wind generation capacity is 16000+ MW and total wind generation is 6%. There are two technologies used in wind generation units: 1.Fixed speed generations 2.Variable speed generation. The fixed generation has designed for particular speed which results in higher efficiency whereas the efficiency is poor for other wind speeds. Variable speed generation have maximum power point tracing capability, it extracts maximum power for different speed which results in maximum efficiency. Also the variable speed generators reduce mechanical stresses on the turbine thus increasing the lifetime of the turbine. Amongst the variable speed generators there are three major kinds, squirrel cage induction generator (SCIG), synchronous generators (SG) with direct power electronic converters and doubly fed induction generators (DFIG) with rotor side power electronic converters. The only difference between the synchronous generators and doubly fed induction generators is the power electronic rating. In a doubly fed induction generator the power electronic converter has a rating of about 30% of the machine rating whereas for the synchronous generator the rating of the power electronic converter is the same as machine rating thereby resulting in higher costs.

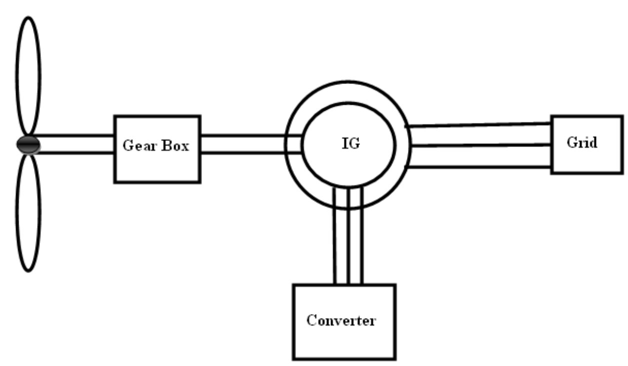

Figure 1. Doubly fed induction generator

Hence DFIGs are mostly preferred one among variable speed generators. This system allows a variable speed operation over a large range. It consists of wound rotor connected to grid through converter and stator circuit is directly connected to grid as shown in Fig. 1. The converter consists of two separate devices with different functions, the generator side converter and the grid side converter. The generator side converter controls the real and reactive power output of the machine and the grid side converter maintains the DC link voltage at its set point. The power electronic converter is also capable of handling power flow in both directions which permits the DFIG to operate at both sub synchronous and super synchronous speeds. Depending upon the operating condition of the drive, power is fed into or out of the rotor, and then it flows from the rotor via the converter to the grid.

Other method of obtaining power from variable speed is connecting converter in between stator and grid. Compared to that doubly fed induction generator has many advantages.

a. Converter is connected to rotor circuit and also only 20%-30% converter only required.
b. It has the ability to control reactive power and to decouple active and reactive power control by independently controlling the rotor excitation current.
c. The DFIG has not necessarily to be magnetized from the power grid, it can be magnetized from the rotor circuit too.
d. It is also capable of generating reactive power that can be delivered to the stator by the grid-side converter. However, the grid-side converter normally operates at unity power factor and is not involved in the reactive power exchange between the turbine and the grid.

But one disadvantage is, due to direct connection of stator to the grid it will be affected during grid disturbances. During voltage dips, over current will be induced in the rotor circuit which may affect the rotor side converter. DFIG can control the reactive power generated during normal operation. However, during grid faults this reactive power controllability disappears or it is very limited. Therefore, it requires additional protection for the rotor side power electronic converter. Conventionally a resistive network called crowbar is connected. When the crowbar is triggered the DFIG becomes a squirrel cage induction generator (SCIG) directly connected to the grid with an increased rotor resistance. During normal operation active and reactive power are controllable and the machine is magnetized by the rotor. However, while the rotor-side converter is disabled and bypassed, the controllability of active and reactive power gets lost and the magnetization is carried out by the stator, as a SCIG. There are several approaches limiting the rotor currents during transient grid voltage dip by changing the rotor side converters control without using external protection devices. It is important to study the behavior of DFIG during voltage dips. Also develop new method to improve the low voltage ride through capability and to prevent islanding of Wind farms during remote fault.

2. Previous Research

There are many research studies has been carried out regarding this topic.

Johan Morre, etal (2005) developed solution. That is to limit the high current in the rotor in order to protect the converter and to provide a bypass for this current via a set of resistors that are connected to the rotor windings. With these resistors, it is possible to ride through grid faults without disconnecting the turbine from the grid. Because the generator and converter stay connected, the synchronism of operation remains established during and after the fault and normal operation can be continued immediately after the fault has been cleared as in [1]. An additional feature is that reactive power can be supplied to the grid during long dips in order to facilitate voltage restoration. A control strategy has been developed that takes care of the transition back to normal operation.

Chai Chompoo-inwai, etal(2005), proposed the effectiveness of applying a fixed-capacitor thyristor controlled reactor (FC-TCR) type of SVC to regulate the terminal voltage of the wind farm, in addition to the traditional fixed capacitor. Chai Chompoo-inwai, et. al(2005) compares the steady-state voltage profile and the voltage ride-through capabilities of the induction-generator-based wind farms with different reactive compensation techniques.

Slavomir Seman, etal(2006) Proposed, coupled field-circuit simulator. The simulator consists of the finite-element method model of a DFIG coupled with the circuit model of the frequency converter, a transformer, and a simple model of the network as in [2].

B.Chitti Babu, K.B.Mohanty (2010), proposed the model, which makes use of rotor reference frame using dynamic vector approach for machine model. It can be suited for modeling of all types of induction generator configurations.

Lasantha Gunaruwan Meegahapola (2010), proposes a decoupled fault ride-through strategy for a doubly fed induction generator (DFIG) to enhance network stability during grid disturbances. The methods have been established to ensure proper coordination between the IG mode and reactive power compensation from the grid-side converter during decoupled operation. Control performance has been benchmarked against existing grid code standards and commercial wind generator systems, based on the optimal network support required (i.e., voltage or frequency) by the system operator from a wind farm installed at a particular location.

3. Effect of Voltage Sag

The number of wind energy installation is rapidly growing worldwide. With increasing wind power production, it is important to predict the grid interaction of wind turbines. In the past, wind turbine generators were allowed to disconnect from the system during faults. Now a days, there is an increasing requirement for wind farms to remain connected to the power system during faults, since the wind power might affect the system stability.

The area of fault ride through capability is one with series implications for system security and thus has implication for the level of penetration of wind generation allowed on the network. During system perturbances the system stability depends on the generators connected to the system to restore the system to normal operation. Disconnection of generation in the event of system faults would lead to local voltage problems, power quality issues and in extreme system collapses.

It was proved by research associates that the grid faults will affect the wind generator. There are different types of fault that may affect the wind farms. The two main faults are Symmetrical and Asymmetrical faults. Symmetrical fault will affect the grid stability more severely. Asymmetrical faults are more difficult to deal.

The problem with a DFIG when a voltage dip occurs is that the stator flux cannot follow the sudden change in stator voltage and a DC component in the stator flux appears. The rotor keeps turning and high slip is generated, which tends to introduce over-voltage and over-current in the rotor circuits due to the effect of speed-voltage. Asymmetrical faults create over currents and over voltages in the rotor because a negative sequence component exists in the stator voltage, and the slip of this negative sequence is very high.

The excess current may damage power electronic converter and over voltage will damage the rotor of induction generator. In order to protect converter connected to the rotor of the generator protecting mechanism is required. Conventionally resistive network called crowbar devices are preferred as in [1]. But the use of crow bar requires additional hardware which increases system complexity and cost. Therefore mostly software modifications in the control strategy are preferred for protecting mechanism.

During normal operation of wind turbine in rotor side converter real power flow will be based maximum power point tracking and voltage at point of common coupling (PCC) and reactive power depends on reference voltage and voltage of DC link capacitor (Vdc). In grid side converter reactive power flow will be zero. Because rotor side converter itself control the reactive power. Real power of the grid side converter depends on the voltage of DC link capacitor and reference voltage from the grid.

When transient fault occurs the crowbar resistive circuit becomes active and reactive power will be controlled by grid side converter. During fault real power will not be supplied by the DFIG. After clearing fault DFIG will come to its normal operation. But grid side converter should be large enough to supply reactive power during fault condition. And also crowbar circuit is additional hardware due to these crowbar resistance and grid side converter; circuit will be very large and high cost.

4. Design of Controller

Controller of the converter circuit is modeled using magnetizing current control (MCC) method. Quadrature component of stator and rotor current is called magnetizing current. Stator flux linkage is induced by this magnetizing current (MC). In this method by controlling magnetizing current damping of stator flux linkage oscillation can be increased. The increase in damping of flux will reduce the oscillation of the rotor current and voltage. Consequently torque power pulsation during voltage sag can be controlled. Block diagram of converter control was shown in fig 2.

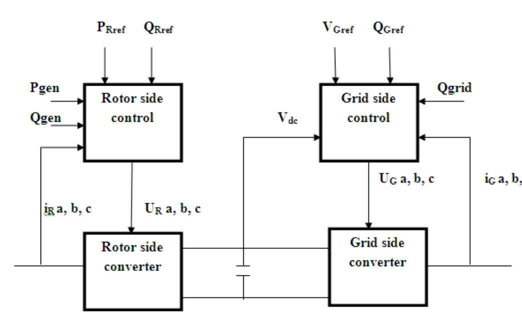

Figure 2. Block diagram of converter controller

So that machine can inject reactive power into the network during fault condition and supply real power after clearing the fault. The rotor current control is much faster than the magnetizing current control method. Although perfect rotor current control is not possible, but in this case by magnetizing current reference error of the current control is smaller. By increasing the controller gain damping get increased, but by increasing gain rotor current also increases. It is necessary to make balance between the damping and maximum current limit of the converter. Magnetizing current control works in parallel with the reactive power control and external to the quadrature rotor current control. This principle offers two main advantages:

a) It is not necessary to detect the voltage sag for the control actuation, because the magnetizing control can be always active.
b) It is possible to control the reactive power even during the sag. This fact is important because the machine can inject reactive current into the grid.

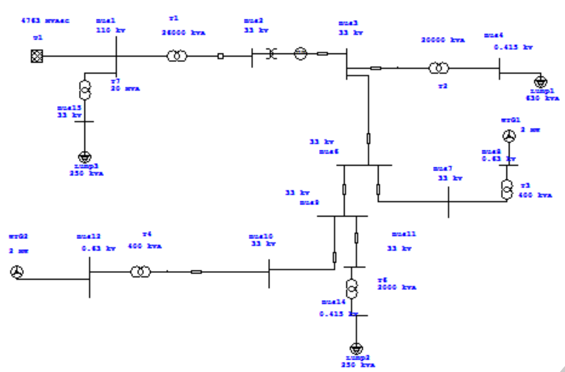

Figure3. System with doubly fed induction generator

5. Simulation Results

The system along with grid was designed. It consists of 15 buses and 2 doubly fed induction generator. Each DFIG generate 2 MW real power during rated wind speed as shown in table 1. Three phase symmetrical fault was created in the remote place from the location of wind turbine generator and fault was cleared after some time. During fault condition DFIG supply reactive power to the grid as shown in Fig. 6. After clearing fault slowly it comes to its normal operation mode by supplying real power as shown in Fig. 5.

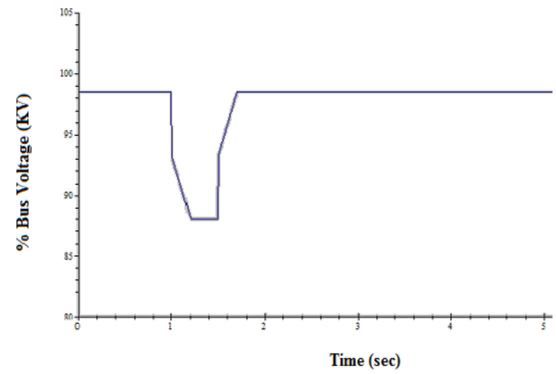

Figure 4. Bus voltage

TABLE I. Wind generator rating

ID	Rating	Rated kV	% Generation
U1	4763.14 MVA	110	-
WTG1	2 MW	0.69	100
WTG2	2 MW	0.69	100
WTG3	2 MW	0.69	100
WTG4	2 MW	0.69	100

Load flow analysis was carried out. It shows the voltage profile of the buses as shown in Fig. 4. Transient stability analysis was carried out it shows the real power and reactive power flow into the grid during and after clearing the fault.

6. Conclusion

When a grid fault occurs on the transmission system, the speed of the generator group increases, the induction generator injects large peak currents, and the plant tends to increment the reactive power consumption so that the voltage dip occurs and it contribute to the collapse of the power network. A simple solution would be the automatic disconnection of the plant from the grid in response to the power fault, but this could lead to a series of disconnections that would produce a massive power-network failure.

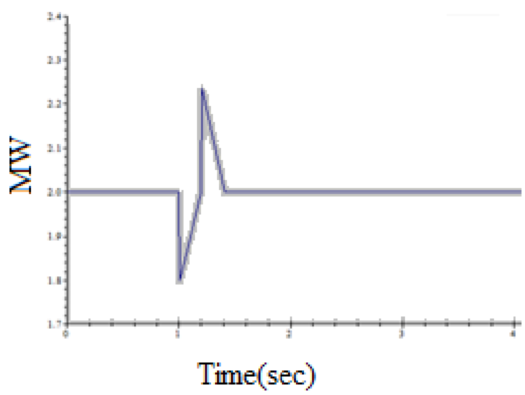

Figure 5. Real power of wind turbine generator

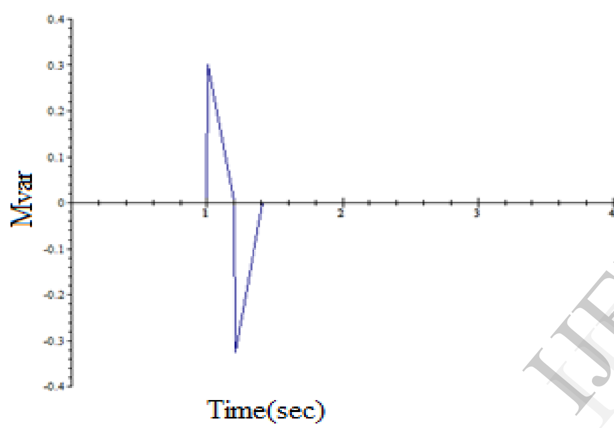

Figure 6. Reactive power of wind turbine generator

Here, only the behaviour of the control strategy during the sag was demonstrated, but it is also useful during the voltage recovering in the end of voltage sag, because in this instant the natural response of the stator flux linkage also appears. Furthermore, the MCC can also be employed during the connection of the generator to the grid, because the voltage transient in the machine stator also causes oscillatory flux response, thereby causing undesired torque and power oscillations. The DFIG behaviour during symmetrical voltage sags was analyzed through simulation results. It was shown that the main problem during balanced dips is caused by the natural response of the stator flux linkage that causes high oscillatory rotor voltages and currents, and, consequently, electromagnetic torque and generated power oscillations. The higher the rotor current control, the higher the decrease in the stator flux linkage damping and the system may become unstable during voltage sag transients. In order to increase the damping of the natural flux, the use of the magnetizing current control was proposed.

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